# Beam Current Improvements on the Axcelis Optima HD Imax Implanter

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**Abstract.** The ability to use large molecular species such as octadecaborane ($B_{18}H_{22}$) has been investigated at semiconductor device manufacturers as a way to significantly increase wafer throughput relative to standard high current ion implanters. Over the past two years, improvements in the machine design to support the use of $B_{18}H_{22}$ have led to beam current increases of 50% from 30pmA to 45pmA of boron at an equivalent boron energy of 4keV. This boron energy is required by p+ doping of dual poly gate (DPG) structures in DRAM. Beam current has also been significantly improved at the low equivalent boron energies anticipated to be required by 32nm processes for PMOS source/drain extensions (SDE). For example, at 250eV equivalent beam energy, a 100% increase in cluster boron beam current has been attained.

This paper describes the techniques by which these beam current improvements were accomplished, primarily through the refinement of ion beam optics. Other techniques for increasing overall tool productivity are also described, such as beam utilization and overall operational improvements. Wafer throughputs are presented for critical p+ implant processes such as dual poly gate (DPG), source/drain (S/D), source drain extension (SDE) and S/D contact. The higher throughputs resulting from these changes are translated into a cost per wafer (CPW) model and it is demonstrated that an increase in average beam current is the largest contributor to a reduction in CPW.

**Keywords:** Ion implantation, high current implanter, wafer scan
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## INTRODUCTION

Over the past few years, the use of large molecular species in ion implantation for the production of semiconductor devices has advanced as the productivity and process benefits are further demonstrated. The productivity opportunity is a direct result of the relatively large effective beam current applied during the doping process. Equipment designers are faced with new challenges to optimize the transport of these large molecules through beamlines that are similar or even directly compatible with those designed for monomer specie transport. Optimization of source and extraction optics, mass analysis and drift regions of the beamline are necessitated to maximize the resultant beam flux available for processing. Traditional ion transport modeling software is utilized for 1st order refinement of these optics; however, the designer must also resort to empirical methods for final conclusions on the aperture geometries.

While beam current improvements offer the largest sensitivity to productivity, other factors such as the ion beam size, ease of setup, beam stability and beam energy also affect the maximum throughput. Further, the beam utilization as determined by the combination of the tools scanning system, coupled with beam size must be considered. Lastly, the use of large molecules and associated vapor pressures require frequent automated cleans which increase the final Cost per Wafer (CPW). Although the cleaning has an impact on the tool utilization, the CPW benefit is positive as compared to conventional implant for the majority of process steps tested including source/drains (S/D), dual poly

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gate (DPG), source drain extensions (SDE) and contact implants.

## Optima HD Imax Architecture

The Optima HD Imax has much in common with the Optima HD, which is the traditional high current ion implanter of the Optima platform [1]. The beamline generates and transports a fixed spot beam which is then coupled to a two dimensionally scanned mechanical endstation. The wafer scanning is accomplished with a fast scan (1– 3m/s) moving the wafer with a horizontal pendulum motion through the beam while a second vertical slow scan (0.1m/s) motion is superimposed on the fast scan. This scanning combination sweeps every point on the wafer through the beam multiple times in order to achieve uniform implants.

The elements of the beamline are shown in Figure 1 and consist of a SemEquip Incorporated 350 molecular source [2], heated extraction electrode, 70 degree analyzing magnet, plasma electron flood and a magnetically suppressed faraday.

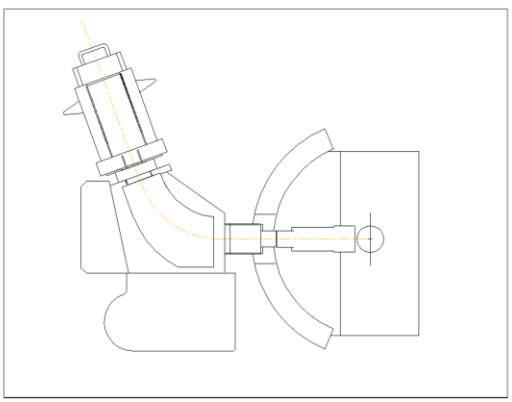

**FIGURE 1.** Optima HD Imax Beamline

The ionization is provided by an electron impact source [3, 4] producing low ion temperatures thus avoiding excessive disassociation of the large molecule. A schematic representation of the source is shown in figure 2. Electrons, emitted from a heated filament, are deflected through $90^{o}$ into the ionization chamber, where they are confined by a permanent magnetic field. Once inside the chamber, the electrons ionize the source feed material and the resultant ions are extracted and accelerated by the electric field defined by the ion source and the suppression and ground electrodes attached to a 2-axis manipulator.

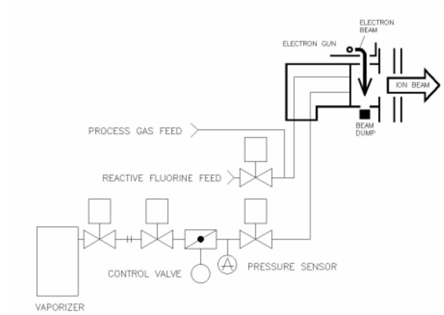


**FIGURE 2:** A schematic representation of the ClusterIon® ion source

The electromagnet for mass analysis is capable of resolving a mass x energy product of 17,600 AMU-keV. Specifically, $B_{18}H_{22}$ can be transported at 80keV with an effective $^{11}B$ energy of 4.2keV. The transport design supports boron hydride species as well as molecular carbon implants of $C_{16}H_{10}$ and $C_7H_7$.

## TECHNIQUES FOR BEAM CURRENT IMPROVEMENT

The paths of the electrons injected into the ionization chamber are controlled by the magnetic fields located around the electron gun and ionization chamber. The second of these fields contains an inflexion point near the entrance aperture which can reflect electrons whose trajectories do not fall within the required acceptance window. By making modifications to the field, the electron trajectories were tailored to optimize the number of electrons injected into the ionization chamber. Additionally, the position of the ion column produced along the path of the electrons was altered to better match a newly modified source aperture.

The new source aperture was developed as part of a program to increase the efficiency of the extraction system. Optical modeling was used to design the extraction optics and match the resultant beam emittance to the acceptance of the Optima HD Imax beamline. Calculations of the ion trajectories were performed using 3-D Lorentz code [5] for a range of extraction, suppression and ground electrode geometries. The output from a typical calculation is displayed in Figure 3.

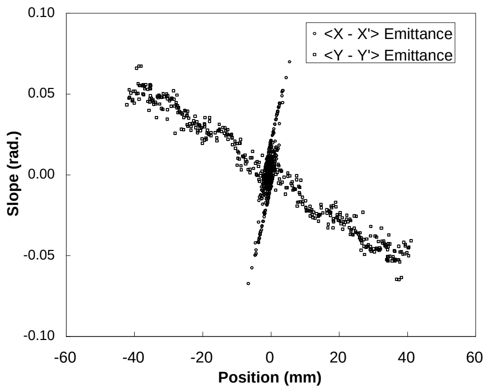


**FIGURE 3:** Modeled emittance plot of the extracted $B_{18}H_{22}$ ion beam

Information from the beam emittance models was subsequently used to represent the starting conditions for a second series of calculations, performed using Transport [6], to determine the transmission efficiency of the ion beam through the beamline. This procedure was conducted for each set of candidate ion optics. Empirical testing was used to fine tune the final electrode designs, which underwent marathon testing under production like conditions in a customer fab. Ultimately different extraction areas were found to be optimal for different extraction energies so that depending on the application, different choices of aperture sizes could be made.

## Beam Utilization

The vertical beam size at the wafer can be adjusted by varying the curvature of the electrodes in the extraction triode (extraction aperture, suppression and ground aperture). Horizontal size at the wafer comes from a combination of horizontal size of the extraction triode and the opening of the resolving aperture. Also, there is an energy dependence to the beam sizes coming from the different magnifications caused by the extraction to suppression gap axis settings. Beam size will also be affected by space charge effects but much less than for standard high current implanters. Utilizing both first order modeling and empirical testing led to the final extraction sizes and curvatures.

The scan optimization of the Optima HD Imax takes into account beam size, fast scan speed and number of slow scans in order to most efficiently implant the desired dose. By adjusting all of these inputs the most efficient beam utilization and thus the highest possible wafer throughput can be obtained.

## RESULTS OF BEAM CURRENT IMPROVEMENTS

Results from extended tests at customer sites indicated that the modifications made to the system allowed octadecaborane ion beams equivalent to atomic boron beams of 45mA at 4keV to be sustained over a 200hr source life [7]. The high beam current at high energy (> 1.5keV) was achieved in part by an increase in the overall transmission ratio of the boron hydride ion beam to 41%.

On the low energy (< 1.5keV) side improvements in ion optics and efficiency allowed for doubling of the beam current down to 250eV effective energies. Shown in Figure 4 are the beam current specifications of the Optima HD Imax, although it should be noted that beam currents in excess of 54 mA (effective) have been demonstrated at effective energies of 4keV. Despite the energy multiplication of the molecular species, which allows for transport at higher energies by a factor of roughly 20, transporting the lowest energies is still the largest challenge to the beamline design.

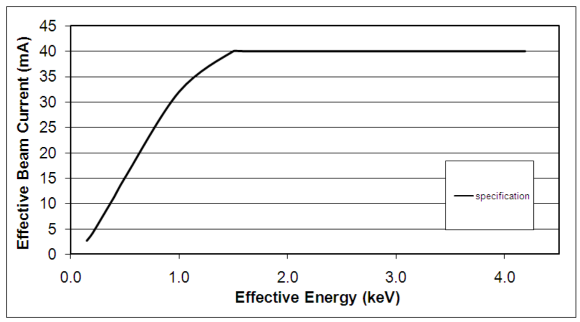


**FIGURE 4:** Beam Current Specification of the Optima HD Imax.

## WAFER THROUGHPUTS

For energies over 1.5keV, the throughput advantage relative to a traditional high current tool is substantial. In Figure 5 is plotted the effective Optima HD Imax throughput vs. dose assuming a beam current of 40mA. Also shown in the same figure is the throughput enhancement relative to a standard high current tool. The standard high current tool was assigned a benchmark beam current of 9ma at 2keV which currently is achieved through the use of deceleration architectures and a comparable drift beam current would be lower.

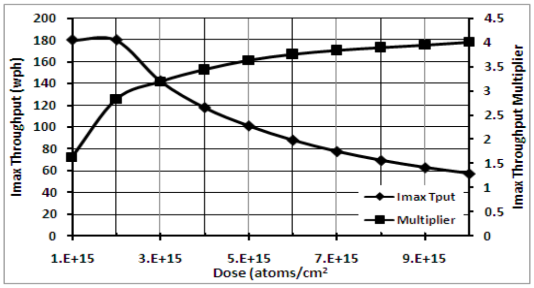


**FIGURE 5: Optima** HD Imax Throughput (wph) vs. Dose and comparison to throughput for standard high current implanter at 2 keV.

## COST OF OWNERSHIP MODELS

The throughput advantages of the Optima HD Imax tool can be translated into cost per wafer production advantages. Shown in Figure 6 is a CPW ratio (Optima HD Imax to standard high current) as a function of beam current. For baseline assumptions the dose is $5 \times 10^{15}$ atoms/cm$^2$ and the standard tool's beam current is again assumed to be 9mA, appropriate for 2keV. In this comparison, the time for cleaning has been incorporated into the analysis and is assumed to be 12%.

Finally, shown in Figure 7 are the sensitivities to a) the cleaning duration and b) time between cleans. Clearly, improved beam current and not down-time due to either of those is the most sensitive knob for CPW.

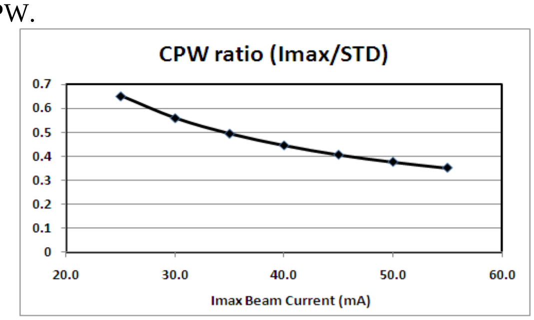


**FIGURE 6:** Cost per Wafer Enhancement: Optima HD Imax relative to standard high current implanter at 2 keV, 5e15 dose, as a function of Optima HD Imax beam current.

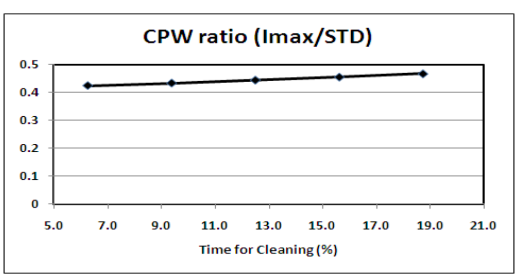


**FIGURE 7a):** Cost per Wafer Enhancement: Optima HD Imax relative to standard high current implanter at 2 keV, 5e15 dose, as a function of time for source cleaning.

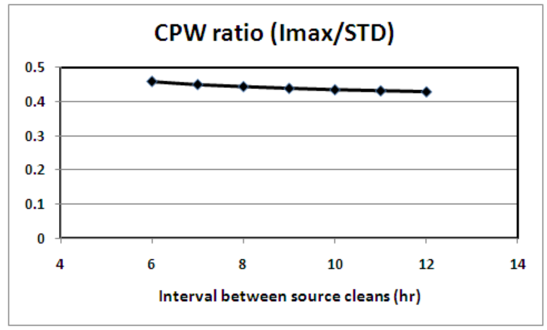


**FIGURE 7b):** Cost per Wafer Enhancement: Optima HD Imax relative to standard high current implanter at 2 keV, 5e15 dose, as a function of interval between source cleans.

## SUMMARY

The Optima HD Imax is a two dimensional mechanical scan machine with molecular implant capability. The ion optics have been optimized as to support the generation and transport of molecular species for boron hydrides and carbon. Together with the beam current improvements, consideration for Cost per Wafer sensitivities such as utilization and operational considerations were provided. The productivity of the tool provides for significant benefits to the semiconductor manufacturer's cost of ownership equation as compared to traditional ion implant.

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